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Polymer stabilized blue phase beam steering

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Nematic liquid crystal (LC) based beam steering have been reported for wide applications [1-3]. However, for conventional nematic LC beam steering the thickness is of several microns in order to have a wider deflection angle. The response time is relatively slow and the diffraction efficiency is low.

The aim of this work has been focused on designing and theoretically analyzing a novel beam steering based on polymer stabilized blue phase liquid crystal (PSBPLC). This special mesophase of the chiral doped nematic LC has several advantageous characteristics. For example, a microsecond response time (approximately ten times faster than NLC) due to the double-twist cylinder diameter and short coherence length. A simulation program estimates the electrical field inside the structure solving the Gauss' law by FEM. An isotropic initial state is considered. The induced birefringence, and the ordinary and extraordinary refractive indices, are calculated in each mesh point. Orientation of the electrical field vector determines the optical axis orientation. The induced optical anisotropy of the PS-BPLC is considered. With this information and adopting the extended Jones matrix, the related electro-optical properties are estimated.

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Abstract:

Nematic liquid crystal (LC) based beam steering have been reported for wide applications. However, for conventional nematic LC beam steering the thickness is of several microns in order to have a wider deflection angle. The response time is relatively slow and the diffraction efficiency is also low.

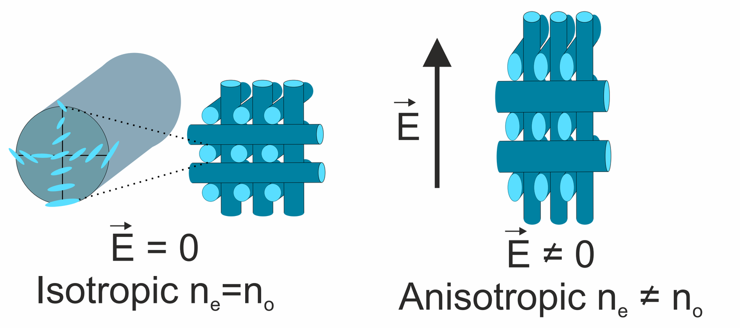
The aim of this work has been focused on designing and theoretically analyzing a novel beam steering based on polymer stabilized blue phase liquid crystal (PS-BPLC). This special mesophase of the chiral doped nematic LC has several advantageous characteristics. For example, an optical isotropic voltage-off state due to the three-dimensional lattice structure, no need of alignment layers because of the self-assembly and a microsecond response time (approximately ten times faster than NLC) due to the double-twist cylinder diameter and short coherence length. A simulation program estimates the electrical field inside the structure solving the Gauss' law by FEM. An isotropic initial state is considered. The induced birefringence, and the ordinary and extraordinary refractive indices, are calculated in each mesh point. Orientation of the electrical field vector determines the optical axis orientation. The induced optical anisotropy of the PS-BPLC is considered. With this information and adopting the extended Jones matrix, the related electro-optical properties are estimated.

1. Theoretical background

1) Induced birefringence and refractive indices:

When a strong electric field E is applied, birefringence is induced with the optical axis along the E vector. Then, the induced birefringence (1) can be estimated by the extended Kerr model [1]:

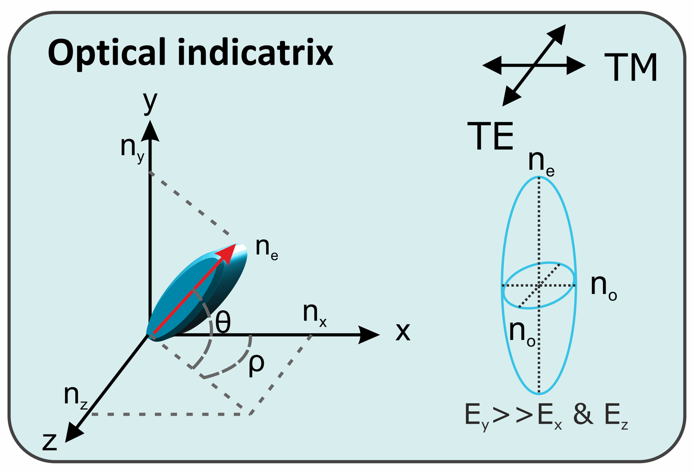
$$\Delta n = \Delta n_s \left(1 - e^{-\left(\frac{|\vec{E}|}{E_s}\right)^2}\right); \quad |\vec{E}| = \sqrt{E_x^2 + E_y^2 + E_z^2}$$



The ordinary (2) and extraordinary (4) refractive indices are also estimated by using this model:

$$n_o = n_i - (1/3)\cdot\Delta n \qquad n_e = n_i + (2/3)\cdot\Delta n$$

2) Optical axis and effective refractive index:



$$\theta = a\tan\frac{E_y}{\sqrt{E_x^2 + E_z^2}}; \quad \varphi = a\tan\frac{E_x}{E_z}$$

$$n_{eff} = \frac{n_o^2 n_e^2}{n_e^2(\sin^2(\theta)\cos^2(\varphi) + \sin^2(\theta)\sin^2(\varphi)) + n_o^2\cos^2(\theta)}$$

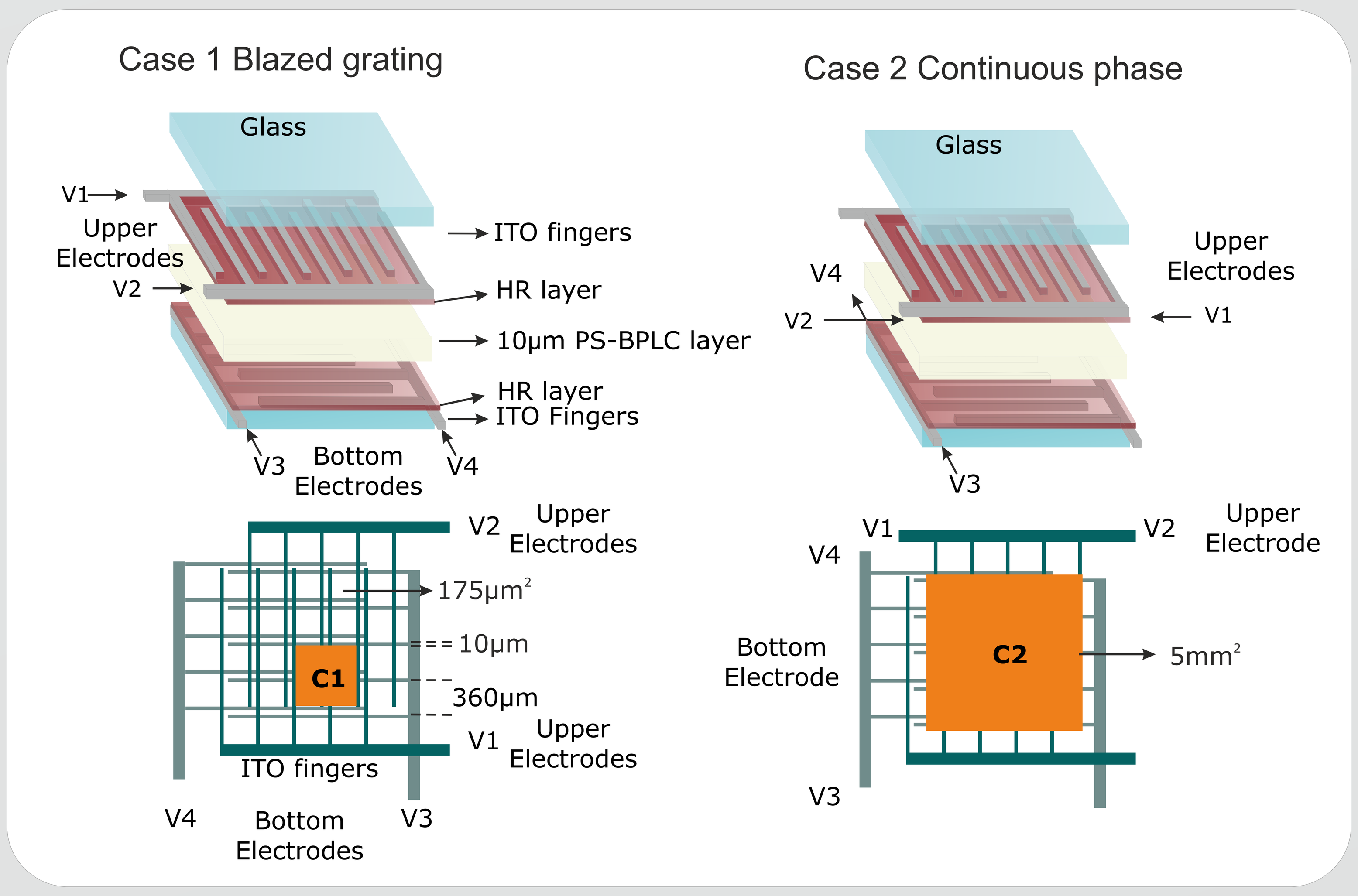
3) Phase retardation ($E_y >> E_x$ & E_z):

$$\Phi_{TM} = \int_0^d \frac{2\pi(n_{eff} - n_i)}{\lambda}; \quad \Phi_{TE} = \int_0^d \frac{2\pi(n_o - n_i)}{\lambda}$$

4) Blue phase characteristics:

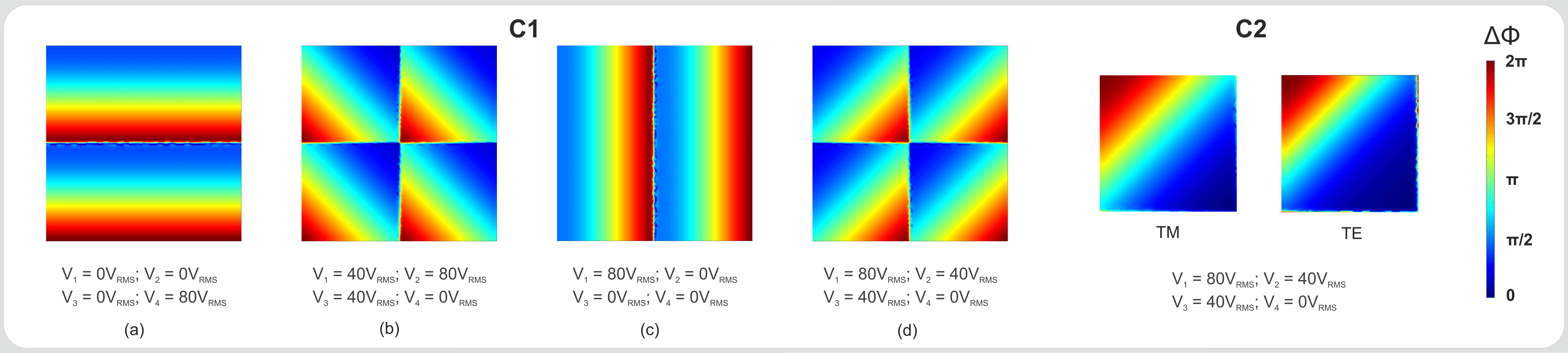
JC-BP01 (n_i=1.5, Δn_s = 0.154, E_s = 4.05 V/µm)

2. Structure



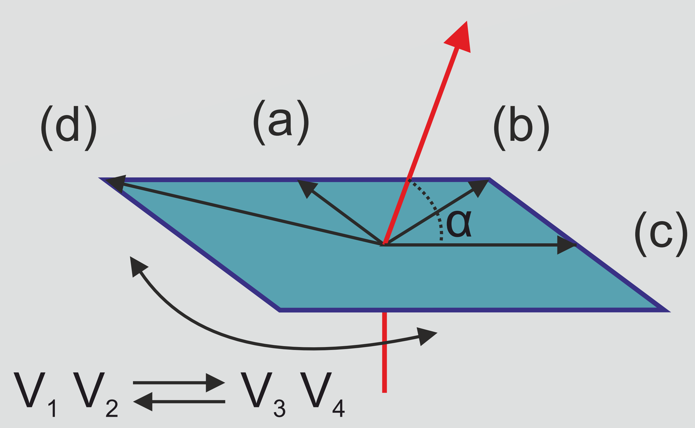
- Case 1: A PS-BPLC blazed-grating beam deflector is obtained. The direction can be controlled by voltage. The deflection angle could be tunable by using a stack of this devices. HR = 10MΩ/sq.
- Case 2: By using only two of the four electrodes (applying the voltage at the sides of the same comb type finger electrode) the phase could by continuous. In this case the deflection angle would be lower but can by tuned by voltage.

3. Results



(a) (b) (c) (d)

Direction and deflection angle



$$\alpha_{1^{st}} = a\sin\left(\frac{\lambda}{\Lambda}\right) = 0.5^{o}@1550\,\text{nm}$$

$$\alpha_{case2} = a\sin\left(\frac{\lambda\Delta\Phi}{2\pi\Delta x}\right) = 0.002^{o}@1550\,\text{nm}$$

- In case 1 the deflection angle for the first diffracted order is 0.5º. A tunable steering is obtained by changing the applied voltage.
- In case 2 the deflection angle can be tuned by changing the amplitude of the applied voltage in each terminal. The beam can be steered to different directions by using the same voltage combination as in the previous structure.

Conclusions:

- **In summary, a novel beam steering based on PS-BPLC was proposed and theoretically analyzed.**
- **This material has several advantages, for example, no need for alignment layers, microsecond response time and an isotropic voltage-off state voltage.**
- **Simulations reveal a control over the phase retardation. The direction of the steered beam can be tuned by voltage. In some cases the deflection angle can be also tuned.**
- **In case 1 a diffractive beamsteerer is obtained (0.5º for 1st order). The second option has a continuous phase (tunable 0.002º).**
- **The phase retardation is the same for the TE and TM modes so unpolarized light could be used.**

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